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THE HYDRA ELECTRON BEAM GENERATOR*

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Summary

The Hydra electron beam generator was designed to simultaneously produce two 1 MV, 0.5 MA, 80 nanosecond electron beams that could be combined to form a single beam. The machine, undergoing final developmental tests, has generated a 0.5 MA, 1 MV peak electron beam from each line. This accelerator consists of a low-inductance Marx generator, two water-dielectric pulse-forming (PF) and impedance-transforming transmission lines and two low-inductance, high-current diodes. A description of the generator is presented along with developmental studies and initial testing data.

The Hydra machine is based on accelerator principles described in the literature.[1,2,3,4] The Marx generator is submerged in transformer oil and separated from the transmission line water by a lucite interface. The Marx charges each coaxial PF transmission line which is deionized water insulated to 3 MV in 0.9 microseconds. At peak voltage, a 3 MV SF6 spark gap electrically connects the 4 ohm PF line to the impedance transforming (4 ohm to 2 ohm) transmission line. The pulse is transmitted through this line to the single radial insulator diode. A 30 kilojoule, 100 nanosecond duration electron beam is formed by a cold cathode in each diode.

Description

The top and side view of Hydra are shown in Figs. 1 and 2. The Marx tank is approximately 14 feet wide, 20 feet long (including the servicing area), and 11 feet deep. Attached to the Marx tank are two water insulated coax transmission lines 4.5 feet in diameter and 4.5 feet long. These lines are mounted to form a convergence angle between the two lines of 15 degrees. The transmission lines then taper down for a distance of 8 feet to the flat surface insulator diodes at the front of the machine. This angulation of the lines allows the two electron beams to be formed with a spacing and direction appropriate for combination and interaction experiments.

The 200 kilojoule Marx generator is composed of 62 stages of 1.85 μfd, 60 kilovolt capacitors of the type specified by the Los Alamos Scientific Laboratory for use in the Scyllac program.[5] The spark gaps are a slightly modified version of the type developed for the Aurora facility by Physics International.[6] The total system inductance is 10 μhenries. Figure 3 is a sketch of the PF transmission line, the SF6 switch, and the impedance transforming transmission line. The outer diameter of the 54-inch long-pulse forming line is 54 inches and the inner cylinder diameter is 30 inches. These dimensions with the water dielectric form a PF line with 4 ohm output impedance and a nominal electrical length of 80 nanoseconds. The SF6 gas trigatron switch is housed in a plastic cylinder, 15 inches outer diameter, 12 inches inner diameter and 15 inches long. This housing has been tested to 180 psig and has operated in the Hydra machine at pressures to 110 psig. The SF6 switch can be externally triggered with the trigger pulse transmitted through a copper sulfate resistor between the inner and outer cylinders of the transmission lines.

Between the SF6 switch and the transmission line is a lucite barrier which capacitively decouples the back of the main SF6 switch from the transmission line. Inside the barrier are six smaller self-breakdown SF6 switches which fire shortly after the incident wave from the PF line arrives. These switches perform a dual function. Firstly, the capacitive coupling from the PF line and the main SF6 switch to the transmission line is greatly decreased. Thus, during charge of the coax line by the Marx generator, the voltage generated across the transmission line and the diode anode-cathode gap is greatly reduced. Secondly, these switches act as open circuits immediately after the main SF6 switch fires and reflect the low voltage portion of the rising wave front. This action effectively decreases the voltage and current rise times.

Because the transmission line is tapered it acts as a short transformer line. In practice, the pulse amplitude can be calculated by assuming no transformer action. The transformer is tapered from an outer diameter of 44 inches to an outer diameter of 32 inches at the tube end.

The diode has a flat disk Plexiglas insulator with a 36-inch outer diameter and a 10-inch inner diameter. The geometry was chosen for ease of cleaning and maintenance and low inductance. This diode is similar to that developed at Naval Research Laboratories.[7] The cathode, located at the center of the tube insulator surface, can be readily changed. The electron beam is formed in the anode-cathode gap and extracted through a 0.5 mil mylar window. The beam can then be drifted externally to the machine.

MAJOR RESEARCH AND/OR PROBLEM AREAS

Marx Generator

The prime requirements for a Marx generator[8,9] are reliability and low inductance. Due to the large number of parts involved in this structure each must have a high reliability. Energies up to 200 kilojoules must be transferred in effective times of 0.3 to 0.4 microseconds from the Marx into the water energy storage lines. The short transfer time is dictated by the time-dependent breakdown characteristics of the water dielectric and is determined by the Marx inductance and associated capacitors. The Hydra Marx generator uses capacitors and spark gaps with proven reliability in a low inductance configuration. Low inductance Marx generators require close spacing between the component parts to minimize magnetic volume. Much of the spacing in Marx generators arises from maintenance requirements. The maintenance requirement has been minimized by designing the Marx so the components can be removed to the service area row by row. The resultant Marx row configuration is shown in Fig. 4. Each row is suspended from an "I" beam by means of rollers and can be easily removed to the provided service area after the Marx tank door is removed. The current passes through the stack entering either one of the capacitors on the right hand side at the top or bottom. The current then passes through the row by traversing alternately through a spark gap and then two series connected capacitors until the opposite end of the row is reached. The opposite end of the row is then connected to the next row by means of an aluminum plate where the current flow is repeated in the reverse direction; with the two nearest current paths in opposite directions,

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the inductance is minimized. By this method, all connections can be made from one side of the Marx. The breakdown characteristics for the Marx gaps are shown in Fig. 5. In the Marx unit, the midplane Marx switch triggers are electrically connected to ground by means of copper sulfate solution resistors. The resistance of these trigger resistors vary according to their location in the generator; the higher the voltage at the gap — the higher the resistance. The electrical schematic for the Hydra Marx charging the PF line is shown in Fig. 6. The Marx unit has been tested to an output voltage of 2.7 megavolts.

Oil-Lucite-Water Interface

An interface (see Fig. 3) separating the oil in the Marx from the water in the fast-pulse lines must withstand mechanical shocks as well as resist surface breakdown. The main problem is tracking along the solid insulator at the water boundary. The interface was designed to provide a uniform electric field over most of the insulator surface and to provide lower fields near the metallic boundaries. The grading of the insulator was performed using a Sandia computer code that solves LaPlace Equation with complex boundaries.[10] This interface has functioned well at 2.7 megavolts.

SF6 Switch

A single channel 200 nanohenry trigatron switch capable of operating to 3.3 megavolts under oil was the prototype for the switch used on the Hydra machine.[11] The Hydra switch is about 20 percent larger in all dimensions. The triggering experiments on the Hydra switch are in the initial stages. The self-firing characteristics, however, are shown in Fig. 7. A major problem developed with the SF6 switch when air bubbles formed on the water side of the insulator surface, causing sparks to form. The discharge caused the insulator housing to rupture. The bubbles have been eliminated by wiping the switch housing in a wetting agent before filling the tank with water. The switch electrode surfaces are fabricated from tungsten-copper (Mallory 10W3) and have carried up to 0.5 MA for pulse lengths exceeding 100 ns. The chemically formed gases and dust are purged from the gap after one to five firings and have presented no problem. As a comparison, a switch using brass electrodes in the same environment became loaded with chemical products after a few firings and had moderate damage to the brass electrodes at current levels of 300 kiloamperes.

Pulse Sharpening Switches

The basic outline of a single switch and its self breakdown versus pressure with 100 ns pulses is shown in Fig. 8. The purpose of these switches is to isolate the transformer and diode from the pulse forming section of the machine until the main switch fires.[12] Inspection of the switch electrodes showed that all six switches had been firing, and from the rise time considerations at the diode it appears that they all fire simultaneously. The voltage wave shape developed across the diode without the switches is shown in Fig. 9, and Fig. 10 is the same waveform with the switches inserted. The 10 to 90 percent tube voltage rise time with and without these switches is 18 ns and 25 ns, respectively.

Diode

The diode is a flat insulator, a design chosen for its low inductance properties. The diode inductance is 36 nanohenries to the cathode mounting plate. The total diode inductance varies widely depending upon the particular type of cathode utilized. The cross sectional view of the diode is shown in Fig. 11. Insulator flashover voltage levels have ranged between 0.5 and 1.0 megavolts for a 100 ns pulse. There are indications that the flashover level is related to the amount of current in the diode and the initial rate of current rise. This in turn suggests that the magnetic field of the generated beam influences the flashover dielectric strength of the insulator. In general, higher current in the diode increased the insulator breakdown strength.

Anode-Cathode Configurations

The first cathode configuration is shown in Fig. 12 and produced five electron beams from one diode. Calorimeter data showed that all five cathodes conduct equally. Witness plates located at the end of a 10-inch common conical drift section at a gas pressure of 2 Torr have demonstrated the 5 beams can be merged to form one beam with a 50 to 80 percent energy loss. The properties of single cathodes of various materials and configurations were also investigated. The results with an empirically determined relationship between cathode radius r, spacing d, and impedance z are shown in Fig. 13. Closure velocities of 10 cm/μsecond have been observed with the V-I traces. The closure velocity is defined as the time between initial voltage application and impedance collapse divided into the anode-cathode gap.

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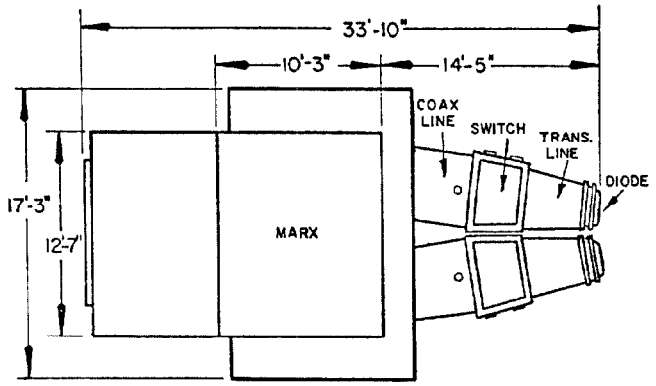


Figure 1
Hydra Tank

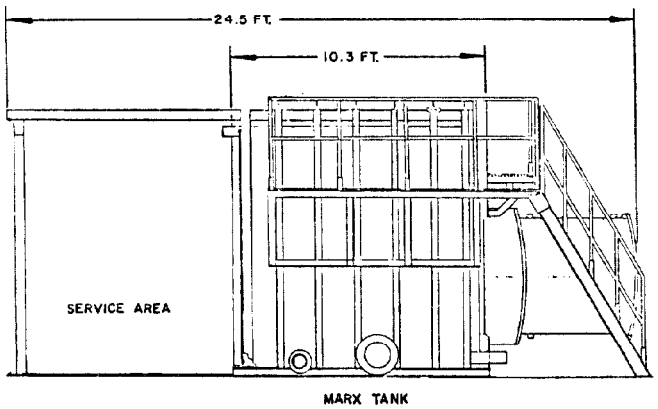


Figure 2
Hydra Tank

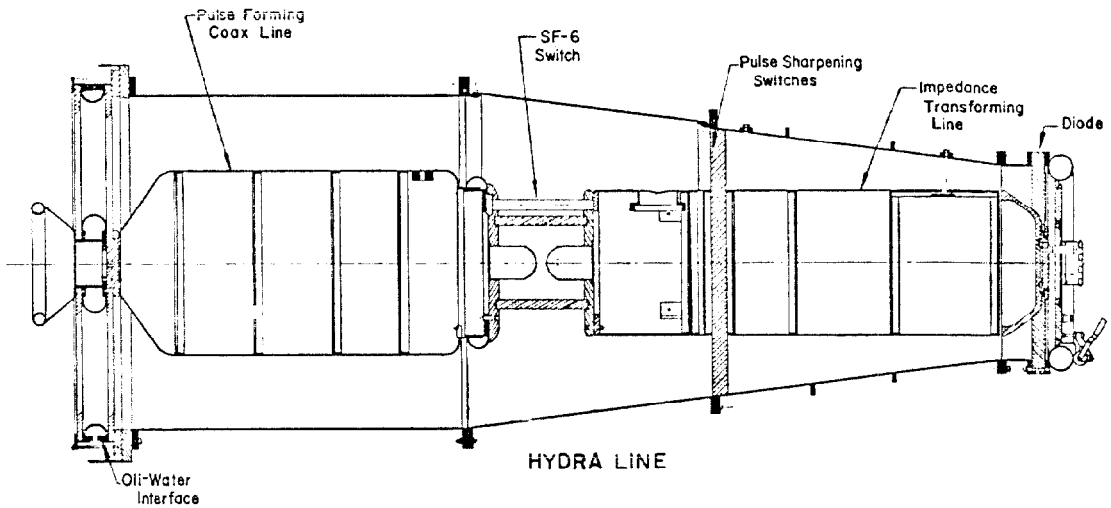


Figure 3

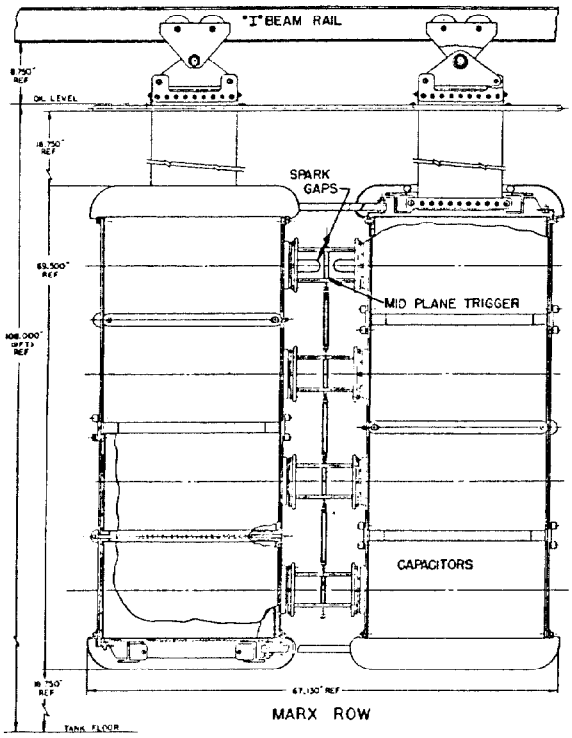


Figure 4

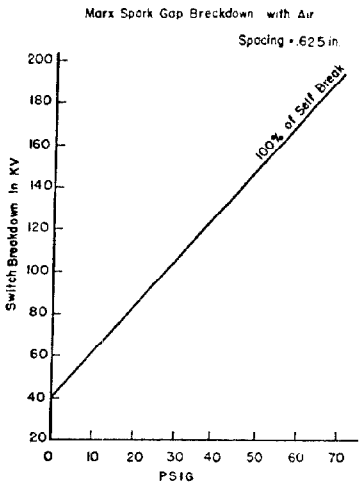
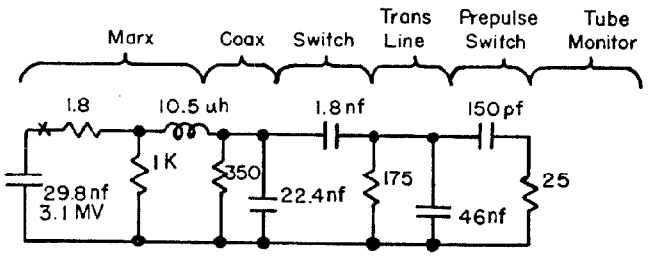


Figure 5

HYDRA EQUIVALENT LUMPED CONSTANT CIRCUIT



Results:

V Coax Peak = 3.12 MV
V Switch = 108 KV
V Prepulse = 304 V
f = 526 KH
$\sqrt{LC}$ = .35 μ sec

Figure 6

PREPULSE SWITCH SF-6 SELF BREAKDOWN

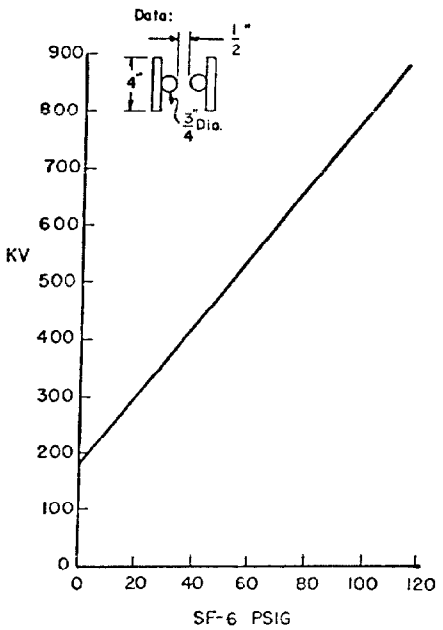


Figure 8

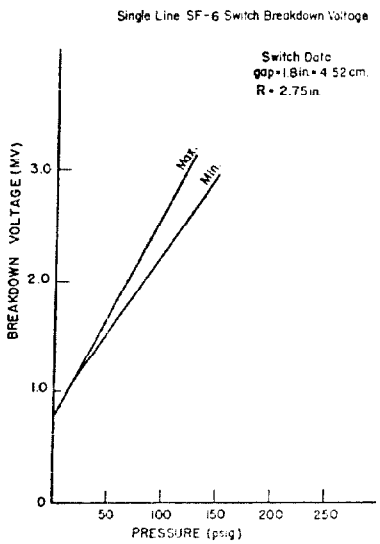


Figure 7

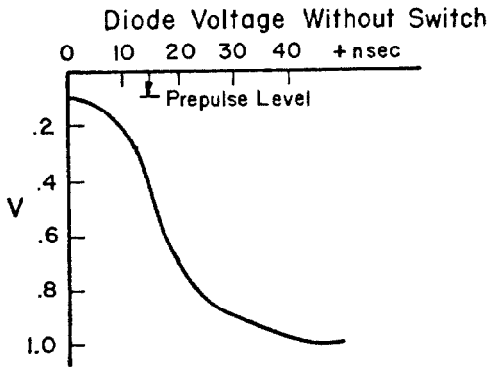


Figure 9

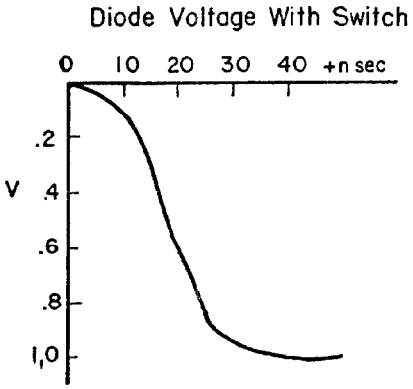
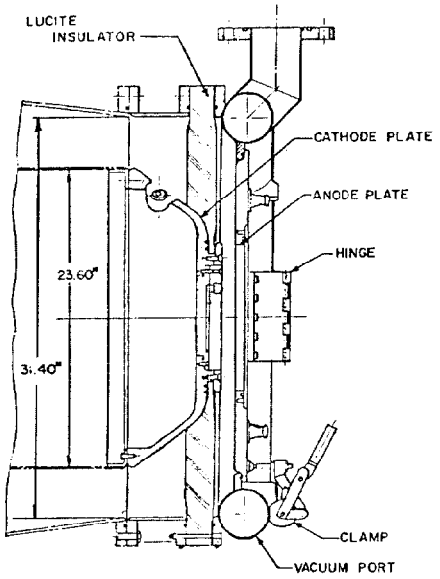


Figure 10



DIODE, MOD. I
(HYDRA)

Figure 11

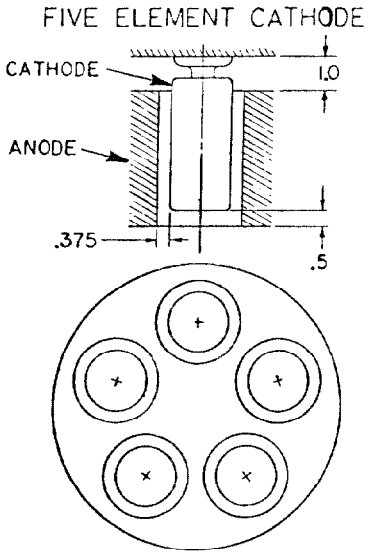


Figure 12

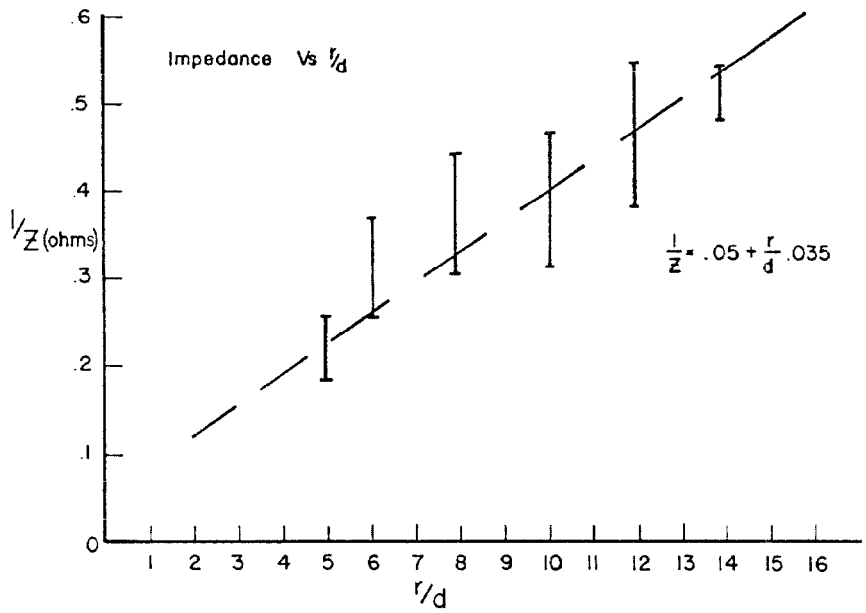


Figure 13